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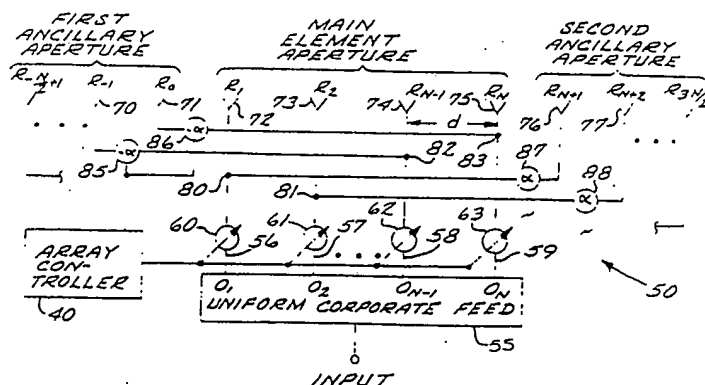
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(54) Title: LOW SIDELOBE PHASED ARRAY ANTENNA USING IDENTICAL SOLID STATE MODULES



(57) Abstract

An electrically scanned phased array with low sidelobes and tapered aperture illumination is disclosed. The array is fed by a uniform corporate feed network (55) and includes a main array aperture formed by main radiating elements (72-75) and first and second ancillary arrays formed by ancillary radiating elements (70-71 and 76-77). For a linear aperture, the outputs from the feed network (55) are phase shifted to steer the beam to one of the available beam locations, and coupled to corresponding ones of the main array radiating elements (72-75) and the ancillary array radiating elements (70-71 or 76-77). The beam steering phase shifts invoke uniform phase gradients between the elements of the respective array, and bi-state phase correctors (85-88) are provided to correct for phase gradient discontinuities across the main and ancillary array apertures. The coupling values between the respective elements of the main array radiating elements (72-75) and the corresponding ancillary array radiating elements (70-71 and 76-77) are selected to provide a desired aperture illumination, such as a tapered aperture illumination. The array may be constructed with identical modules, resulting in improved performance at lower cost.

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LOW SIDELOBE PHASED ARRAY ANTENNA
USING IDENTICAL SOLID STATE MODULES

BACKGROUND OF THE INVENTION

1 The invention relates to phased array antennas
employing active RF modules containing transmit and/or
receive amplifiers, and more particularly to a technique
for achieving low sidelobes in such an antenna.

5 Phased array antennas which employ feed networks
and comprising active transmit/receive microwave modules
have been implemented and described in the literature.

Techniques for controlling the sidelobes of such
systems also exist. One technique which has been used in
10 the past to achieve low transmit sidelobes (tapered
aperture illumination) is to use modules with different
power outputs. This provides a stepped aperture distri-
bution which produces low sidelobes adjacent the beam.
Disadvantages of this technique are:

- 15 1. The steps in the aperture distribution lead
to high sidelobes in the region away from the beam.
2. The requirement of modules having different
power outputs leads to higher production cost.
3. The different output powers of the modules
20 are obtained by varying the number of solid state devices
in the output stage. This requires different combiners

1 with different losses and phase error, thus making the
system more complex.

4. Different driver chains are required leading
to phase and amplitude tracking (between modules) over
5 the frequency band thus tending to increase the
sidelobes.

To get a tapered amplitude, varying the modules'
supply voltages will change output power; however, the
dc-to-rf efficiency decreases and phase tracking is
10 difficult, particularly in the class C amplifiers often
used. The use of class A amplifiers will produce varying
output by simply varying the input; however, the
efficiency will be poor since typically a 10 dB output
power variation is required.

15 Another technique which requires only identical
modules is to decompose the transmit aperture into equal
power segments which necessarily contain different
numbers of radiating elements for a tapered illumination.
This requires phase shifters downstream from the transmit
20 amplifiers introducing one-way losses of 1 dB or more.

One purpose of the invention is to provide an
electronically scanned phased array antenna for radiating
low sidelobe beams using identical solid state modules
without the aforementioned disadvantages.

25 Another purpose of the invention is to provide a
phased array antenna ~~which employs identical modules to~~
achieve radiation patterns having low sidelobe levels,
and avoids the need for lossy phase shifters between the
transmit amplifiers and radiating elements.

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SUMMARY OF THE INVENTION

The foregoing and other purposes and features are provided by the invention in a phased array employing a uniform corporate feed network coupled to $2N$ radiating elements. In a first embodiment, the corporate feed network divides the array input signal into N feed outputs of equal power and phase. N beam steering phase shifters are coupled to corresponding ones of the feed outputs. A first set of N main radiating elements are spaced apart to form a linear main radiating aperture. Second and third sets of $N/2$ ancillary radiating elements are disposed in respective spaced relationships to each end of the main aperture to form first and second ancillary element radiating apertures.

In a second embodiment, the ancillary elements are disposed at only one end of the main aperture.

The main element and ancillary element apertures in both embodiments form a linear composite array aperture. Means are provided for coupling each phase shifted feed output to a main radiating element and corresponding one of the ancillary radiating elements such that a uniform phase gradient is invoked between the respective elements of the main element aperture and the respective elements of the ancillary element apertures. Bi-state phase correctors are employed to correct the phase of the respective signals applied to the ancillary elements to achieve phase continuity between the respective adjacent elements of the main aperture and the ancillary aperture. The coupling means, the beam steering phase shifters and the bi-state phase correctors preferably form N modules. By appropriate control of the beam steering phase shifters and the bi-state phase shifters, the beam

1 generated by the array may be scanned through a set of discrete angles.

In another embodiment, the array further comprises circulator/duplexers, low noise amplifiers and additional coupling elements to eliminate the lossy high power
5 bi-state phase correctors and provide two receive channels. In another embodiment, a two-dimensional array system is provided, by which the signal driving each main element is coupled to two ancillary elements and in yet
10 another embodiment, a two-dimensional array is provided by which the signal driving each main element is coupled to three ancillary elements. In each of the embodiments, substantially identical modules are used so that they are interchangeable with others within the embodiment.

15 BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will become more apparent from the
20 following detailed description of exemplary embodiments thereof, as illustrated in the accompanying drawings, in which:

FIG. 1 is a schematic circuit diagram depicting a transmit array comprising N basic elements combined with
25 N additional elements to provide an extended array of $2N$ elements fed by an array of phase shifters connected to a uniform corporate feed.

FIG. 2 is a plot of the phase of an exemplary aperture distribution for the extended array of FIG. 1, illustrating the phase correction supplied by the inven-
30 tion between the main aperture and ancillary apertures to achieve a continuous linear phase progression over the aperture.

1 FIG. 3 is a plot of the amplitude of an exemplary tapered amplitude distribution for the extended array of FIG. 1, illustrating the respective amplitude from a main element and the corresponding coupled element.

5 FIG. 4 is a simplified array beam pattern illustrative of beams which may be formed from the basic array of FIG. 1 when the phase shifters provide the same discrete phase gradients as an N element Butler or multiple beam matrix.

10 FIG. 5 is a simplified array beam pattern illustrative of the discrete beams using the discrete Butler phase shifts which may be formed with the extended array of FIG. 1.

15 FIG. 6 depicts the usage of a Magic T power divider to achieve the desired phase and amplitude for each pair of elements in the extended array of FIG. 1.

FIG. 7A is a simplified schematic diagram of one exemplary transmit module embodying one aspect of the invention.

20 FIG. 7B is a schematic block diagram of an array system employing the transmit modules depicted in FIG. 7A.

25 FIG. 8A is a plot of the amplitude of an exemplary tapered amplitude distribution for the extended array of FIG. 1 resulting in the 27.5 dB sidelobes shown in FIG. 8B, and which were obtained by trial and error.

30 FIG. 9 is a schematic circuit diagram depicting another line source embodiment comprising N basic elements combined with N additional elements to provide an extended array of 2N elements in a side-by-side configuration.

1 FIG. 10A is a simplified schematic diagram of an
exemplary transmit/receive module for monopulse
operation.

5 FIG. 10B is a schematic block diagram of an array
system employing the transmit/receive modules depicted in
FIG. 10A.

 FIG. 11 is a schematic diagram and a perspective
view of a solid state transmit/receive module package in
accordance with the invention.

10 FIG. 12A-12C illustrate three respective
embodiments of the basic transmit circuit employed in
accordance with the invention.

 FIG. 13 is a schematic depiction of the connections
between the basic arrays of a two dimensional array and
the ancillary arrays employed in accordance with the
invention.

 FIG. 14 is a simplified schematic diagram of the
interconnected apertures forming the two dimensional
array of FIG. 13.

20 FIG. 15 is a simplified schematic diagram of an
embodiment of a transmit module embodying the invention
for the two dimensional array of FIGS. 13 and 14.

 FIG. 16 is a simplified schematic diagram of an
embodiment having one main element and three ancillary
elements in a planar array.

25 FIG. 17 is a simplified schematic diagram of an
embodiment of a transmit module usable in the array of
FIG. 16.

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DETAILED DESCRIPTION OF THE DISCLOSURE

5 The basic operating principles of the invention may be better understood by considering first a transmit array 50 as shown in FIG. 1. A uniform corporate feed 55 with outputs 56-59 of equal amplitudes and phases feeds an array of N phase shifters 60-63 and N radiating ele-
10 ments 72-75. The number N is assumed to be even in the following discussion of the preferred embodiment.

 Although the term "transmit" has been used in various places herein, those skilled in the art will recognize that reciprocity dictates an identical or at
15 least similar operation in a receive mode. Therefore, the term "transmit" is used in those instances only for convenience of description and may in fact include the operation of receive. Likewise the term "radiative" may also include "receptive".

20 Phase shifter 60 has a coupler 80 which feeds elements 72(R_1) and 76(R_{N+1}), phase shifter 61 has a coupler 81 which feeds elements 73(R_2) and 77(R_{N+2}), phase shifter 62 has a coupler 82 which feeds elements 74 and 70, and phase shifter 63 has a coupler 83 which feeds
25 elements 75 and 71.

 Phase correctors 85-88 respectively couple element 70 to coupler 82, element 71 to coupler 83, element 76 to coupler 80, and element 77 to coupler 81. Each serves to provide a phase shift α between the respective pairs of
30 elements.

 Array controller 40 provides control signals to the respective phase shifters 60-63 and 85-88 to control the respective phase shifts introduced by these elements.

35 The array comprising radiating elements 72-75 may be viewed as forming a main element aperture, the array com-

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1 prising elements 70 and 71 a first ancillary array aper-
 2 ture, and the array comprising elements 76 and 77 a second
 3 ancillary array aperture. If a phase gradient ψ between
 4 the radiating elements is invoked in the beam steering
 5 phase shifters 60-63, the same gradient exists at all
 6 three apertures. However, there is a phase discontinuity
 7 at the boundaries between the main array aperture and the
 8 two ancillary apertures. This phase discontinuity is
 9 illustrated in FIG. 2, where the solid lines depict the
 10 phase of the array aperture distribution as a function of
 11 distance across the aperture. The phase correctors 85-88
 12 are provided to adjust the phases at the ancillary ele-
 13 ments 70, 71, 76, 77 to eliminate the phase discontinuity.
 14 The magnitude of the phase shift α of the phase correctors
 15 85-88 is chosen to produce phase continuity between
 16 elements 71(R_0) and 72(R_1), and between elements 75(R_N)
 17 and 76(R_{N+1}), resulting in a continuous linear phase
 18 across the resultant array aperture comprising the main
 19 aperture and the first and second ancillary apertures.
 20 The corrected phase of the first and second ancillary
 21 apertures is illustrated by the dotted lines in FIG. 2.
 22 Further, the beam produced by the resultant aperture may
 23 be scanned in space by varying the beam steering phase
 24 gradient ψ and the correcting phase shift α .

25 The coupling values of the couplers 80-83 may be
 26 chosen to produce a tapered aperture illumination which
 27 satisfies the energy conservation relation between ampli-
 28 tudes A_n and A_{n+N} (arising from the couplers) at elements
 29 n and $n+N$,

$$A_n^2 + A_{n+N}^2 = \text{constant}, \quad -\frac{N+1}{2} < n < \frac{N+1}{2}$$

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1 The selection of the appropriate coupling values of
the couplers 80-83 is illustrated in FIG. 3, showing the
amplitude of an exemplary tapered aperture distribution as
a function of distance over the aperture of the array of
5 FIG. 1. This exemplary distribution is a tapered one for
achieving low sidelobes in the array pattern off the beam.
The position of exemplary element R_1 is indicated in FIG.
3, as is the position of the corresponding element R_{1+N} in
the second ancillary array which is coupled to element R_1 .
10 Given the desired distribution and the positions of the
radiating element, the desired amplitudes at each radiat-
ing elements is readily obtained. The required coupling
factor may be calculated from the desired corresponding
amplitudes of the respective elements. For example, in
15 FIG. 3 the distribution amplitude at element R_1 varies as
 $\cos\beta$, while the amplitude at element R_{1+N} varies as $\sin\beta$,
with β representing the power coupling factor of the
coupler ($\cos^2\beta + \sin^2\beta = 1$).

20 In the general case, the phase progression between
elements and the phase correction α may be selected to
scan the array beam at any desired beam angle. The corre-
sponding values of the phase shift α necessary for a
continuous linear phase across the extended aperture may
be calculated in the following manner. The output voltage
25 at each radiating element for uniform amplitude and
constant phase progression ψ is

$$v_n = e^{j(n-\bar{n})\psi} \quad n = 1, \dots, N, \quad \bar{n} = (1+N)/2 \quad (1)$$

30 Smooth phase progression requires

10

1
$$\frac{V_{N+1}}{V_N} = e^{j\psi} \quad \text{where} \quad (2a)$$

5
$$V_{N+1} = V_1 e^{ja} \quad (2b)$$

Substituting Eq. 1 with n equals 1 or N , and Eq. 2b into Equation 2a yields the relation of Eq. 3.

10
$$e^{j(N\psi-a)} = 1 \quad (3)$$

To satisfy Eq. 1 for arbitrary ψ , the phase correctors 85-88 are variable over the range 0° - 360° . At the
15 current state of the art, such phase shifters are available, but may introduce significant losses which are undesirable for some applications.

The phase correctors 85-88 can be simplified or eliminated for a particular set of values of the phase
20 progression ψ , the phase shifts which are characteristic of the Butler matrix.

The uniform corporate feed 55 and the beam steering phase shifters 60-63 of FIG. 1 may be viewed as functioning as the equivalent of one portion of an N -port (N
25 inputs and N outputs) Butler matrix. The corporate feed 55 and phase shifters 60-63 provide only a single beam at any given time, but different beams can be generated by changing the phase shift ψ of the shifters 60-63. The general Butler matrix can produce simultaneously N
30 equally spaced beams, each with a gain of N times the element gain. Butler matrices are well known in the art, and are described, for example, in "Multiple Beams from Linear Arrays," J.P. Shelton and K.S. Kelleher, IEEE

- 1 Trans. Antennas and Propagation, Vol. AP-9, page 154,
March 1961.

Eq. 1 set forth the phase relationship for the
phase shifts which are characteristic of a Butler matrix

$$5 \quad \psi = \frac{2\pi}{N} (m - \bar{n}), \text{ with } \bar{n} = (1+N)/2, m=1\dots N \quad (4)$$

With these characteristic phase shifts, an array of
N equally spaced radiating elements fed by an N port
10 Butler matrix produces beams as shown in FIG. 4, i.e.,
 $\sin x/x$ patterns with 4 dB crossover. By using the cou-
plers 80-83 feeding 2N elements to form the extended
apertures as shown in FIG. 1, and with the phase shifters
60-63 providing the set of phase shifts specified in Eq.
15 4, the resultant array aperture of FIG. 1 is twice as
large as the Butler matrix and the beams directed in the
same directions are approximately half the width (exactly
half for all equal power splits), as indicated in FIG. 5
by the beams in solid lines. Beam crossovers are very
20 low (at the nulls for equal power split couplers). J.P.
Shelton, "Reduced Sidelobes for Butler Matrix Fed Linear
Arrays," IEEE Trans. Antennas and Propagation, Vol.
AP-17, page 645, September, 1969.

To obtain full coverage over the scanned area, it
is necessary to fill in the missing beams (shown in
25 phantom lines in FIG. 5) using the beam steering phase
shifts

$$\psi = (2\pi/N) (m - \bar{n} + 1/2) \quad m = 1, \dots, N \quad (5)$$

30 If the progressive phases given by Eqs. 4 or 5 are
substituted into Eq. 3, and multiples of 2π are discarded,
then $\alpha = \pi$ or 0, respectively, if N is even and $\alpha = 0$ or π

1 if N is odd. In either case, N even or odd, it is neces-
 sary to have two phase states $\alpha = 0$ or π in order to
 satisfy Eq. 5. Thus, the main element R_n and the corre-
 sponding element R_{n+N} or R_{n-N} are either excited in phase
 5 for one set of beams ($\alpha = 0$) or out of phase for the
 second set of beams ($\alpha = \pi$). With ψ and α so chosen, the
 phase is continuous between elements R_0 and R_1 as well.
 Thus, the phase correctors 85-88 for the special case of
 the Butler phase shifts specified by Eqs. 4 and 5 are
 10 simplified to bi-state phase correctors having the two
 possible states 0 and π .

The couplers 80-83 may be chosen to produce a
 tapered amplitude distribution and the progressive phase
 shift provided by the beam steering phase shifters 60-63
 15 may be chosen to place beams at discrete angles θ given by

$$kd \sin \theta = \psi \quad (6)$$

where d is the radiating element spacing, k is $2\pi/\lambda$, λ is
 20 the wavelength, θ is the angle from the normal to the
 array, ψ is given by Equations 4 or 5 and α is either 0 or
 π .

The loss incurred by the bi-state phase correctors
 85-88 is typically 1 dB at the present state of the art.
 25 These devices can be eliminated by using phase to produce
 both the desired amplitude and phase α . If the sidearms
 of a magic T coupler device are excited by two equal
 amplitude signals $1/(2)^{1/2}$ with phases $+\phi_1$ and $-\phi_1$, the sum
 arm output is $\cos \phi_1$ and the difference arm output is \sin
 30 ϕ_1 , where ϕ_1 is selected to produce the correct power
 split. This is depicted in FIG. 6 which illustrates a
 circuit which is the equivalent of one of the beam steer-

1 ing phase shifters 60-63 and the corresponding one of the
bi-state phase correctors 85-88 of FIG. 1.

5 The circuit of FIG. 6 utilizes a magic T four port
coupler, a coupler which is well known to those skilled in
the art, and described, for example, in "Microwave Antenna
Theory and Design," edited by Samuel Silver, 1965, 1949,
Dover Publications, at page 572. In the magic T circuit
of FIG. 6, a fixed $\pi/2$ lag has been added such that both
signals are real. If ϕ_1 is replaced by $-\phi_1$, the sum
10 signal remains the same at $\cos\phi_1$, but the difference arm
signal changes sign; consequently the function of the
coupler 80-83 in the previous discussion is determined by
the choice of the magnitude of the phase ϕ_1 and the
function of the bi-state phase shifters 85-88 is deter-
15 mined by the sign of ϕ_1 . An alternate realization of this
circuit is to replace the magic T with a quadrature hybrid
function and program a fixed $\pi/2$ phase difference between
the phase shifters which produce $\pm\phi_1$.

20 The basic modular building block 100 of the present
invention for the transmit mode is shown in FIG. 7A. The
module 100 comprises beam steering phase shifter 102 for
providing one of the characteristic Butler phase shifts
 $\phi = n\pi(2m-2\bar{n})/N$ or $n\pi(2m+1-2\bar{n})/N$. Phase shifters 104 and
106 supply respective phase shifts of $\pm\phi_1$ and $\mp\phi_1$ to pro-
25 vide the power splitting and phase correction functions as
described above with respect to FIG. 5.

The outputs of the phase shifters 104 and 106 are
provided as inputs to identical solid state high power
transmit amplifiers 108 and 110. The amplifier outputs
30 are connected to respective sidearms of magic T coupler
112. The output of the sum arm of the magic T, the signal
 $\cos\phi_1 e^{j\phi}$ for a unit input signal at input port 124, is

1 coupled to radiating element R_n . The output of the
 difference arm of the magic T is shifted in phase by $-\pi/2$
 to provide the signal $j\sin\phi_1 e^{j\phi}$, coupled to radiating
 element R_{n+N} .

5 The beamsteering functions provided by the phase
 shifter 102 in FIG. 7A can be combined with the functions
 of the phase shifters 104 and 106; then only two phase
 shifters are required, one producing $\phi \pm \phi_1$ and the other
 $\phi \mp \phi_1$.

10 The utility of the module embodiment of FIG. 7A may
 be appreciated by considering several examples. The array
 controller 40 (shown in FIG. 7B) may control the phase ϕ
 of the beam steering phase shifters 102 of each module in
 accordance with Eq. 4 or Eq. 5 to steer the beam to the
 15 desired one of the $2N$ discrete beams. The magnitude of
 the phase shift ϕ_1 of phase shifters 104 and 106 may be
 set to zero. The value ϕ_1 selects the aperture
 distribution by controlling the relative power split
 between the main aperture radiative element and the
 20 corresponding ancillary aperture radiative element. With
 ϕ_1 set to zero, no power is provided to the ancillary
 aperture elements ($\sin 0 = 0$) and the transmit signal
 power will be divided equally among the N radiative
 elements comprising the main element aperture.

25 A second illustrative example is the case for the
 phase shift $\phi_1 = \pi/4$ radian or 45° . In this case, the
 power in the transmit signal at each module is divided
 equally between the main element and the corresponding
 ancillary element. Thus, a uniform aperture distribution
 30 is provided over the entire extended array of $2N$ radiative
 elements. This distribution maximizes the gain over a
 beam width which is one half that produced by the first
 example ($\phi_1 = 0$).

1 The phase value ϕ_1 may be selected to provide the tapered illumination described above, which minimizes the sidelobe level of the resultant radiation pattern, as will be appreciated by those skilled in the art.

5 A further principal advantage of the embodiment of FIG. 7A is that substantially all signal power provided by the high power amplifiers 108 and 110 is delivered to the radiative elements, since there are no lossy devices between the amplifiers and the radiative elements.

10 FIG. 7B illustrates a line source transmit array employing N transmit modules M_1 to M_N , each comprising a module as described in FIG. 7A. The array of FIG. 7B is similar to that of FIG. 1, except that the transmit modules M_1 to M_N have replaced the separate beam steering phase shifters 60-63, the couplers 80-83 and the bi-state
15 phase correctors 85-88. Thus, the uniform corporate feed network 55 divides the single input signal into N network output signals of equal amplitude and phase. Each of the modules M_1 to M_N is identical to the others.

20 Even with ideal elements there is a limit to the sidelobe level which can be produced by modules strictly of the form shown in FIG. 7A. This arises because of the constraint imposed by the magic T couplers 112 on the aperture distribution. This constraint may be written in
25 the following form for a continuous symmetrical distribution over an aperture of length D.

$$A^2(x) + A^2\left(\frac{D}{2} - x\right) = 2A^2\left(\frac{D}{4}\right) \quad , \quad (7)$$

- 1 where x represents distance along the aperture.
 For example, the cosine distribution

$$A(x) = \cos(\pi x/D) \quad (8)$$

- 5 satisfies the constraint and produces 23 dB sidelobes. A second aperture distribution is shown in FIG. 8A and produced the 27.5 dB sidelobes shown in FIG. 8B. These results were obtained using a trial and error technique.
 10 Those skilled in the art may use more sophisticated trial and error techniques to achieve lower sidelobes. However, a condition will ultimately be reached where sidelobes cannot be lowered further without excessive beam broadening and lower gain.

- 15 In this case, the use of slight loss may produce lower sidelobes with higher gain as follows.

- For a desired distribution $B(x)$ (such as Taylor distribution which does not satisfy the constraint of Equation 7), there is an optimum distribution $A(x)$
 20 satisfying Equation 7 which may be modified by attenuation to produce $B(x)$ with maximum efficiency. It can be shown that this distribution is given in terms of a function $\gamma(x)$ as follows:

$$25 \quad A(x) = \sin \gamma(x) \quad 0 \leq x \leq D/4 ; \quad (9a)$$

$$= \cos \gamma(D/2-x) \quad \frac{D}{4} \leq x \leq \frac{D}{2} ; \quad (9b)$$

$$\tan \gamma(x) = B(x)/B(D/2-x) \quad 0 \leq x \leq \frac{D}{4}$$

30 The resulting efficiency is:

$$\text{Efficiency} = \frac{\int_0^{D/2} B^2 dx}{4K^2/D} \quad (10)$$

Where $1/K^2$ is the minimum value of $B^2(x) + B^2(D/2-x)$ in the interval $0 \leq x \leq D/2$. For example, if $B(x) = \cos \pi x/D$, $\gamma = \pi/2 - \pi x/D$, $A(x) = B(x)$ and there is no loss. For a 32 dB Taylor series distribution $\bar{n} = 4$ distribution calculations show the efficiency loss is $-.48$ dB, a small price to pay in most practical cases.

Another line source embodiment is shown in FIG. 9. In this embodiment, half of the circuit of FIG. 1 has been deleted. This embodiment comprises N main elements and N ancillary elements. In this embodiment, N need not be even. Pairs of elements, e.g., R_1 and $R_N + 1$, are interconnected through a coupler, such as that designated by numeral 90 and α phase shift is used with the ancillary elements in a manner correspondingly similar to that described above for FIG. 1. The embodiment of FIG. 9 is not restricted by the even number of elements requirement of FIG. 1. In FIG. 1, the surrounding of main elements by ancillary elements requires that an even number of main elements be used, i.e., a number divisible by four, since an unbalance would occur with a different number of elements in the first ancillary aperture from that number in the second ancillary aperture. The embodiment of FIG. 9 has no such restriction and any number of main elements may be used.

The discussion of the operation of the embodiment of FIG. 1 is applicable to the embodiment of FIG. 9 except that the phase of aperture distribution across the array aperture will have only one discontinuity as

1 opposed to the two discontinuities shown in FIG. 2. That
discontinuity, however, is corrected by means
corresponding to the correction between the main array
and the second ancillary array of the embodiment of FIG.
5 1.

A planar array embodiment of the invention suitable
for transmit and receive operation is shown in FIGS. 10A,
10B and 11. To provide the capability for the monopulse
receive mode, circulator/duplexers and low noise ampli-
10 fiers are inserted near each radiating element of the
array. With sufficient gain, these amplifiers establish
the signal-to-noise ratio such that lossy power division
and attenuation can be used downstream without penalty.
An exemplary transmit/receive (T/R) module 130 is shown
15 in FIG. 10A. The T/R module 130 comprises transmit
module section 100 (depicted in FIG. 7A). Transmit
signals from the transmit corporate feed 55 are provided
as inputs to transmit input port 124 of each T/R module.
The module sections 100 are coupled to radiating elements
20 R_n and R_{n+N} via respective attenuators 116, 118 and
circulators 120, 122.

The receive section 150 of module 130 is coupled to
the radiating elements R_n and R_{n+N} via circulator/duplex-
ers 120, 122 and low noise amplifiers 158, 162. The
25 section 150 provides receive sum and difference signals
at ports 172, 154. The outputs from amplifiers 158, 162
are respectfully coupled to the sum arm and to the
difference arm of magic T couplers 178, 180 of the
receive section 150. The difference arm and the sum arm
30 of these respective couplers are terminated in matched
loads 190, 192. One sidearm of magic T coupler 178 is
coupled through attenuator 174 to the sum port of magic T
coupler 194; the other sidearm of magic T coupler 178 is

1 coupled through attenuator 182 to the sum arm of magic T
coupler 196. Similarly, one sidearm of magic T coupler
180 is coupled through attenuator 176 to the difference
arm of magic T 194; the other sidearm of magic T coupler
5 180 is coupled through attenuator 184 to the difference
arm of magic T coupler 196.

The outputs of the sidearm of magic T coupler 194
are respectively phase shifted by $\pm\phi_3$ (phase shifter 168)
and $\mp\phi_3$ (phase shifter 170) and combined. The resultant
10 signal is phase shifted by the beam steering phase shift
 ϕ (phase shifter 166) to provide the receive difference
signal at port 154.

The outputs of the sidearms of magic T 196 are
respectively phase shifted by $\pm\phi_2$ (phase shifter 186) and
15 $\mp\phi_2$ (phase shifter 188) and combined. The resultant
signal is phase shifted by ϕ degrees by beam steering
phase shifter 172 to provide the receive sum signal at
sum port 172. The circuitry enclosed by phantom lines
169 and 199 in FIG. 8A is functionally similar to
20 transmit circuit 100 with the amplifiers 108, 110
omitted.

The power splitting and phase correcting phase
shift devices 104, 106, 168, 170, 186, and 188 are
respectively controlled by an array controller (not
25 shown) to select the appropriate one of the two states of
these phase shifters to form the desired beam.

Independent transmit, receive sum and receive
difference channel patterns are obtainable by choosing
the phase shifts $\pm\phi_1$, $\pm\phi_2$, and $\pm\phi_3$ and the attenuation
30 levels of attenuators 116, 118, 182, 184, 174 and 176 (if
necessary at all for ultra low sidelobes). All modules
in an array are preferably identical, except for these
attenuators. The phase shifts $\pm\phi_1$, $\pm\phi_2$, and $\pm\phi_3$ are

1 determined by computer software control, and are variable
during operation to produce different patterns, should
that be desired for clutter or interference rejection
purposes. Thus, the respective phase shifts ϕ_1 , ϕ_2 , ϕ_3
5 may be independently selected to achieve desired aperture
amplitude distributions for the respective transmit,
receive sum and receive difference patterns.

FIG. 10B is a schematic diagram of an array system
employing the transmit/receive modules 130 depicted in
10 FIG. 10A to provide transmit, receive sum and receive
difference channels. In this example, the $2N$ radiating
elements are coupled to the transmit corporate feed
network 55 by the transmit/receive modules TR_1 - TR_N . Each
radiating element has a particular duplexer, attenuator
15 and low noise amplifier set (122, 118, 162 or 120, 116,
158) associated with it, as shown in FIG. 10A.

The respective outputs 172, 154 of each
transmit/receive module TR_1 - TR_N are coupled to the
respective uniform corporate feed networks 132 and 134 to
20 provide the receive sum channel and receive difference
channel signals, respectively. The networks 55, 132 and
134 are identical.

The modules TR_1 - TR_N of FIG. 10B may be fabricated
as identical modules whose physical configuration is
25 illustrated generally in the schematic perspective view
of FIG. 11. The module includes RF connections for the
transmit signal input T , the two receive signals RC_1 and
 RC_2 , and the connections to the radiating elements R_n and
 R_{n+N} , power and control signal lines. In addition, the
30 attenuators 116, 118, 182, 184, 174 and 176 may be pro-
vided in the form of plug-in elements. Further, the low
noise amplifiers 158, 162 and circulators 120, 122 may be
incorporated into the respective modules. Thus, each

1 module is identical except for the value of the attenua-
tors.

In the special case of uniform transmit
illumination one can compare the use of this technique
5 with the usual identical module per element approach.
For this special case, both arrays produce the same
patterns with 13 dB sidelobes, have the same number of
transmit modules, circulator/duplexers, and low noise
amplifiers. The array employing the present invention
10 does have more passive circuitry and low power phase
shifters. The array employing the invention, however, is
able to produce a tapered aperture distribution and
provide the low sidelobes not otherwise achievable with
identical modules alone.

15 Alternate embodiments of the transmit circuit 100
which do not employ magic T couplers may be constructed
using 90° hybrid couplers. FIG. 12A illustrates the
basic transmit circuit 100 of FIG. 10A with circulators
120', 122' and attenuators 116', 118' added. FIG. 12B is
20 a first alternate embodiment 100" of the circuit
representation of FIG. 12A which employs 90° (quadrature)
hybrid couplers 111" and 113" in place of the magic T
coupler 112', eliminating the need for the fixed phase
shifter 114' of FIG. 12A. Further, quadrature hybrids
25 are easier to construct in stripline or microstrip
transmission lines than magic T couplers.

Quadrature hybrid couplers are well known to those
skilled in the art, and comprise two pairs of ports. If
one port of one pair is driven by a unit signal (i.e., of
30 value one) then the power at the corresponding through
port of the second pair will be $1/(2)^{1/2}$, the power at the
coupled port of the second pair will be $-j/(2)^{1/2}$, and the
power at the other port of the first pair will be zero.

Thus, assuming a unit input to module 100", one output coupled to radiative element R_n has the amplitude $T_1 \cos \phi$, and the output to the corresponding ancillary element R_{n+N} or R_{n-N} has the amplitude $T_2 \cos \phi$, with T_1 and T_2 being the corresponding attenuation values for attenuators 116" and 118", and ϕ is the magnitude of the phase shift introduced by phase shifters 104" and 106".

FIG. 12C illustrates a third embodiment 100''' of the transmit module which is a preferred embodiment because of practical hardware characteristics. In this embodiment, the circulators 120''' and 122''' and attenuators 116''' and 118''' are placed between the hybrid couplers 111''' and 113''', in contrast to the module configuration of FIG. 12B. This placement has several practical advantages. One advantage is that the circulators 120''' and 122''' carry the same power levels, whereas one of the circulators 120' and 122' of FIG. 12A or one of the circulators 120" and 122" of FIG. 12B may carry most of the power in highly tapered aperture distributions. Thus, the power rating of the circulators may be reduced by a factor of about 50%. A second advantage is that the attenuators 116''' and 118''' within a module have the same attenuation value relaxing phase tracking. Finally, residual tracking corrections are easier to implement in software for the circuit of FIG. 12C.

The attenuators T_3 in the embodiment of FIG. 12C have the attenuation value $T_3^2 = T_1^2 \cos^2 \phi + T_2^2 \sin^2 \phi$. The magnitude of the phase shift of phase shifters 104''' and 106''' is $\psi = \tan^{-1}[(T_2 \sin \phi)/(T_1 \cos \phi)]$.

A third embodiment of the invention is depicted in FIGS. 13-15. This embodiment is a two-dimensional array, wherein the techniques described above respecting FIGS.

1 1-11 are extended to two dimensions. In FIG. 13, a basic
 planar array of $N \times L$ radiating elements is divided into
 four quadrants. Each radiating element in the basic
 array is coupled to two other elements at $A(n,m)$. For
 5 basic element $A(n,m)$ in the lower left quadrant, for
 example, one of the ancillary elements is located in an
 ancillary array at $A(n+N,m)$, and the other element is
 $A(n,m+L)$. The three elements are coupled by a three-way
 power divider, with β_1 representing the power division
 10 factor between the main element at $A(n,m)$ and the
 ancillary element at $A(n+N,m)$, and β_2 representing the
 power division factor between the main element and the
 ancillary element at $A(n,m+L)$. For unit power inputs,
 the basic element at $A(n,m)$ may have output power $(\cos^2 \beta_1$
 15 $+\cos^2 \beta_2)/2$ and each of the two ancillary elements have
 power $\sin^2 \beta_1/2$ and $\sin^2 \beta_2/2$, respectively, thereby
 satisfying energy conservation at the three-way divider
 fitted to each basic element. Each quadrant may contain
 numerous radiating elements.

20 The choices of the division factors β_1 and β_2 of
 each basic element allow an amplitude taper to be applied
 to the array. Each basic element has two ancillary
 elements; therefore, the added area of the aperture is
 twice that of the basic area. The requirement of certain
 25 discrete phase shifters (for the special case discussed
 above of the characteristic Butler phase shifts) and the
 0 or π additional phase shifts necessary to obtain full
 volumetric coverage by a pencil beam are the same as for
 a linear array due to the separability of the beam-
 30 steering phases.

This technique is extended to the remaining three
 quadrants in the basic area producing a total aperture
 which has three times the area of the original basic

1 array. The areas which are connected directly are shown
in FIG. 14 where A_n represents an element in the n th
quadrant of the basic array and B_n and C_n are the ancil-
lary areas.

5 The transmit building block 200 for the two-dimen-
sional array is shown in FIG. 15, and requires two magic
T couplers 214, 232, one combiner T 218, and four equal
level power amplifier modules 210, 212, 228, 230. These
elements are located in two substantially identical
10 modules 201 and 221. In these modules, the amplifier
modules 210, 212, 228, and 230 are also substantially
identical. Also substantially identical are the phase
shift devices 206, 208, 224, and 226. Their phase shift
values may be controlled as shown in FIGS. 10B and 11.

15 Two high power amplifier modules 228, 230 of phases
 $\pm\beta_1$ and relative power $1/4$ each are combined in magic T
232 to produce outputs as $\cos\beta_1/(2)^{1/2}$ and $\pm\sin\beta_1/(2)^{1/2}$, the
latter output being connected at port 234 to an ancillary
element.

20 The two high power amplifier modules 210, 212 are
phased $\pm\beta_2$ and combined in magic T 214 to produce outputs
as $\cos\beta_2/(2)^{1/2}$ and $\pm\sin\beta_2/(2)^{1/2}$, the latter being connected
at port 216 to the other ancillary element.

The two sum outputs of respective magic Ts 214, 232
25 $(\cos\beta_1/(2)^{1/2} + \cos\beta_2/2)$ and $(\cos\beta_2/2)$ are combined in a combiner T 218
to provide at port 220 the output power $(\cos^2\beta_1 + \cos^2\beta_2)/2$.

The values of β_1 and β_2 are selected to provide the
tapered amplitude distribution. Beamsteering is accom-
30 plished by the setting of the phase shift of phase
shifter 204. Resistive loading may also be used for
additional tapering and sidelobe reduction. The receive
mode function of operation is obtained by inserting

1 duplexers at each element and constructing circuits
similar to the transmit circuit, as described above for
the one dimensional (linear) array. Independent sum and
difference patterns can be obtained as in the case of the
5 linear array.

Another planar array embodiment using three
ancillary elements with each main element thereby forming
a group of four elements is shown in FIG. 16. This
allows a full rectangular aperture with a tapered,
10 separable aperture distribution. An element, $A_{n, m}$ in
the main array is connected to the same two elements as
in FIG. 13 ($A_{n+N, m}$ and $A_{n, m+L}$), but an additional
ancillary element ($A_{n+N, m+L}$) is also employed. The
entire array comprises quartets of elements disposed in
15 the pattern shown in FIG. 16 except translated and/or
rotated. The total area of the array is now four times
greater than the main array.

The radiation pattern resulting from this
embodiment has main sidelobes in the principal planes
20 only (vertical and horizontal planes when the beam is
broadside). Thus the 27.5 dB sidelobes for the linear
array can be produced by this planar array as well.

A simplified interconnection of four elements is
shown in the module schematic, FIG. 17. The input is
provided at terminal 301. Four elements 300, 302, 304,
25 306 are connected to 3 dB hybrid junctions 308, 310, 312,
314, which are connected in turn to amplifiers 316 and
phase shifters 318. The phase shifter settings shown in
FIG. 17 produce the four outputs indicated at the
30 elements 300, 302, 304, 306 assuming unit input and
disregarding amplifier gain. There is substantially no
loss, and amplitude tapering can be modified by changing
the phase shifters only. The input with unit magnitude

1 may be phase shifted such that a beam comprising the
contributions of each quartet can be steered in space in
small discrete steps as in the previous planar array
embodiment. Also the π phase shifter requirement can be
5 met by changing the sign of the ϕ_1 and ϕ_2 phases as
required for beam steering in both planes. Duplexers may
be added at the element level for independent receive
beams, or between the amplifiers 316 and output hybrids
308, 310, 312, 314, just as in the linear array module of
10 FIG. 12C.

A solid state electrically scanned phased array
with low sidelobes (tapered aperture illumination) using
identical solid state modules has been disclosed. The
advantages of this invention include the following:

15 (1) Easier engineering design since only one
module type need be considered.

(2) Lower production cost since the entire array
is composed of only one module type.

20 (3) Improved phase and amplitude tracking between
modules and improved radiation pattern performance since
the modules are all identical and need only be built
similarly to achieve the phase/amplitude tolerance.

(4) High efficiency transmitter operation since
all transmit sections are identical and may be tuned for
25 optimum performance (efficiency, bandwidth, gain, output
power, low noise) while still maintaining the ability to
achieve a tapered aperture illumination and consequent
low sidelobes in both transmit and receive modes.

30 (5) Rapid (pulse to pulse in a radar)
selectability of pattern characteristics, i.e., change
beamwidth, sidelobe level, depending on system mode of
operation, jamming and clutter environment.

1 (6) Amplitude and phase type adaptive nulling
capability on receive.

5 It is understood that the above-described embodi-
ments are merely illustrative of the possible specific
embodiments which can represent principles of the present
invention. Other arrangements may be devised in accor-
dance with these principles by those skilled in the art
without departing from the scope of the invention.

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CLAIMSWhat is claimed is:

1 1. A phased array having a plurality of equally
spaced radiating elements, dividing means for dividing
(55) an input signal into N feed outputs (56-59) of
equal power and phase, and means for applying phase
5 shift (60-63) for steering beams of the array,
characterized in that:

the radiating elements comprise a group of N main
radiating elements (72-75) equally spaced to form a
linear main element aperture;

10 the radiating elements also comprise N ancillary
radiating elements (70, 71, 76, 77) disposed outside the
group of said main radiating elements (72-75) and in
linear alignment therewith to form said at least one
ancillary aperture;

15 said means for applying phase shift comprises N
beam steering phase shifters (60-63) for use in steering
the beam in a desired direction, one each coupled to a
corresponding feed output (56-59) and supplying phase
shifted feed outputs, and

20 comprises coupling means (80-83, 85-88) for
coupling each phase shifted feed output to a main
radiating element and to a corresponding ancillary
radiating element and for applying phase shift to the
signals applied to said ancillary radiating elements to
25 achieve linear phase continuity between the elements of
the main aperture and those of the at least one
ancillary aperture such that a uniform phase gradient is
invoked across the apertures.

1 2. The array according to Claim 1 further
characterized in that the coupling means comprises

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amplifier means (108, 110) for amplifying said feed outputs after phase shift has been applied.

1 3. The array according to any preceding claim
further characterized in that said coupling means is
responsive to a control signal for adjusting the
relative power in said respective main and ancillary
5 element signals to provide a desired array aperture
amplitude distribution.

1 4. The array according to Claim 3 further
characterized in that said coupling means comprises N
identical modules (100), one for each of the N phase
shifted feed outputs (56-59), and each module provides
5 one of said main element signals and said respective
ancillary element signal.

1 5. The array according to Claim 4 further
characterized in that each of said modules (100)
comprises:

means for dividing said respective feed signal into
5 first and second signal components of equal amplitude;

first means for phase shifting (104) said first
signal component by the positive or negative of a
selected phase value;

10 second means for phase shifting (106) said second
signal component by the negative or positive of said
selected phase value;

said first and second means for phase shifting are
responsive to said control signal for selecting said
phase value and the corresponding positive or negative
15 sign associated therewith; and

means for receiving said first and second phase
shifted components and providing said main and ancillary
module outputs therefrom, wherein the amplitude of said

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20. main output signal is proportional to the cosine of said selected phase value, and the amplitude of said ancillary output is proportional to the positive or negative of the sine of said phase value, the value of said selected phase value being selected to provide the desired array aperture amplitude distribution.

1 6. The array according to any preceding claim
further characterized in that said N ancillary radiating
elements (70, 71, 76, 77) are disposed such that N/2
radiating elements are disposed in a uniformly spaced
5. relationship adjacent each end of said main element
aperture to form first and second ancillary element
arrays.

1 7. The array according to Claim 1 further
characterized in that said N ancillary radiating
elements are disposed in a uniformly spaced relationship
adjacent one end of said main element aperture to form
5. an ancillary element array.

1 8. The phased array according to Claim 1 wherein
the array is two dimensional, further characterized in
that:

5. the dividing means (55) divides the input signal
into N x L feed outputs of equal power and phase;

said means for applying phase shift comprises N x
L beam steering phase shifters (204) for use in
steering the beam in a desired direction, one each
coupled to a corresponding feed output (202) and
10. supplying phase shifted feed outputs,

said radiating elements comprise a matrix of
rectilinear N main elements by L main elements forming a
two dimensional main element aperture;

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15 said radiating elements also comprise a matrix of
ancillary elements, each ancillary element comprising a
plurality of radiative elements, said ancillary elements
being disposed outside of and adjacent said main
elements matrix such that two ancillary elements are
20 disposed in a rectilinear relationship with a respective
main element;

first (220), second (216), and third (234) output
terminals;

means for coupling said first output terminal to a
radiating element of a main element;

25 means for coupling said second and third output
terminals to respective radiating elements in said
respective ancillary elements disposed in said
rectilinear relationship with said main element;

30 said coupling means is also for processing each
said phase shifted feed output to provide first, second,
and third output signals and for connecting said first,
second, and third output signals to said first (220),
second (216), and third (234) output terminals
respectively, said coupling means also for controlling
35 amplitudes to achieve a desired array aperture amplitude
distribution, and said coupling means also for
controlling phases so that said second and third output
signals are selectably in phase or out of phase with
said first output signal to result in a uniform phase
40 gradient between said main and respective ancillary
elements;

wherein said coupling means comprises:

second dividing means for dividing said feed
output into a plurality of signals;

45 phase correcting means (206, 208, 224, 226) for
applying a phase correction of either zero or 180
degrees to the plurality of signals to achieve linear

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phase continuity between the main aperture elements and their respective ancillary elements; and

50 a plurality of substantially identical amplifiers (210, 212, 228, 230) for amplifying the phase corrected plurality of signals.

1 9. The phased array according to Claim 1 wherein the array is two dimensional, further characterized in that:

the dividing means (55) divides the input signal
5 into N x L feed outputs of equal power and phase;

said means for applying phase shift comprises N x L beam steering phase shifters for use in steering the beam in a desired direction, one each coupled to a corresponding feed output (301) and supplying phase
10 shifted feed outputs,

said radiating elements (300, 302, 304, 306) comprise a matrix of rectilinear N main elements by L main elements forming a two dimensional main element aperture;

15 said radiating elements also comprise a matrix of ancillary elements, each ancillary element comprising a plurality of radiative elements, said ancillary elements being disposed outside of and adjacent said main elements matrix such that three ancillary elements are
20 disposed in a rectilinear relationship with a respective main element;

first, second, third and fourth output terminals;

means for coupling said first output terminal to a radiating element (300) of a main element;

25 means for coupling said second, third, and fourth output terminals to respective radiating elements (302, 304, 306) in said respective ancillary elements disposed in said rectilinear relationship with said main element;

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30 said coupling means is also for processing each
said phase shifted feed output to provide first, second,
third and fourth output signals and for connecting said
first, second, third, and fourth output signals to said
first, second, third, and fourth output terminals
respectively, said coupling means also for controlling
35 amplitudes to achieve a desired array aperture amplitude
distribution, and said coupling means also for
controlling phases so that said second, third, and
fourth output signals are selectably in phase or out of
phase with said first output signal to result in a
40 uniform phase gradient between said main and respective
ancillary elements;

wherein said coupling means comprises:

second dividing means for dividing said feed
output into a plurality of signals;

45 phase correcting means (318) for applying a phase
correction of either zero or 180 degrees to the
plurality of signals to achieve linear phase continuity
between the main aperture elements and their respective
ancillary elements; and

50 a plurality of substantially identical amplifiers
(316) for amplifying the phase corrected plurality of
signals.

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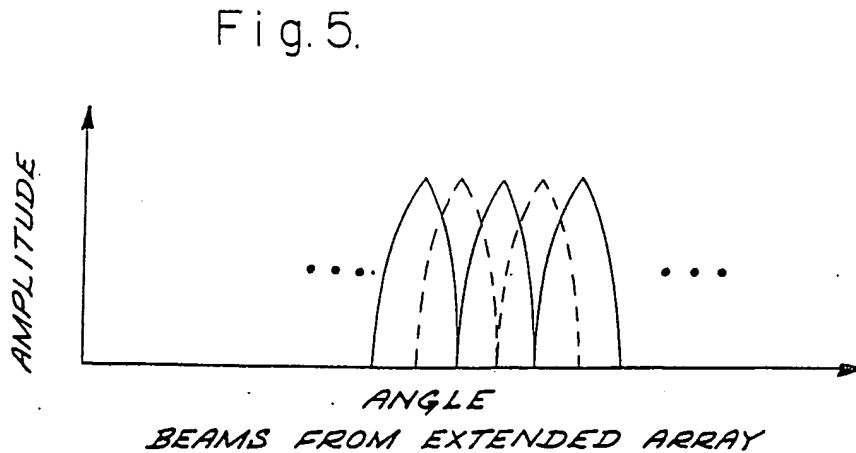
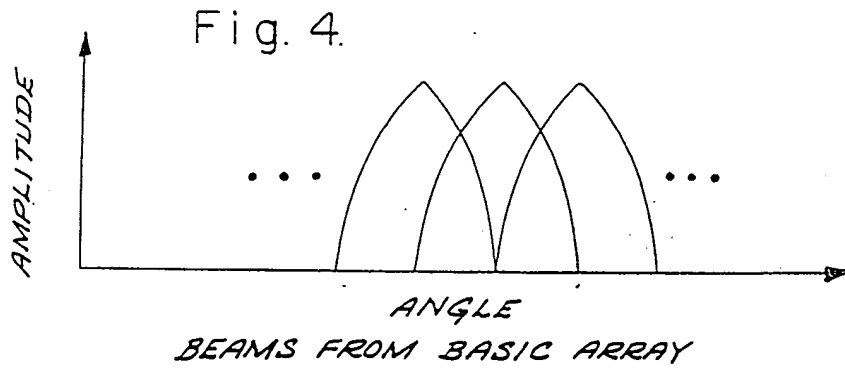
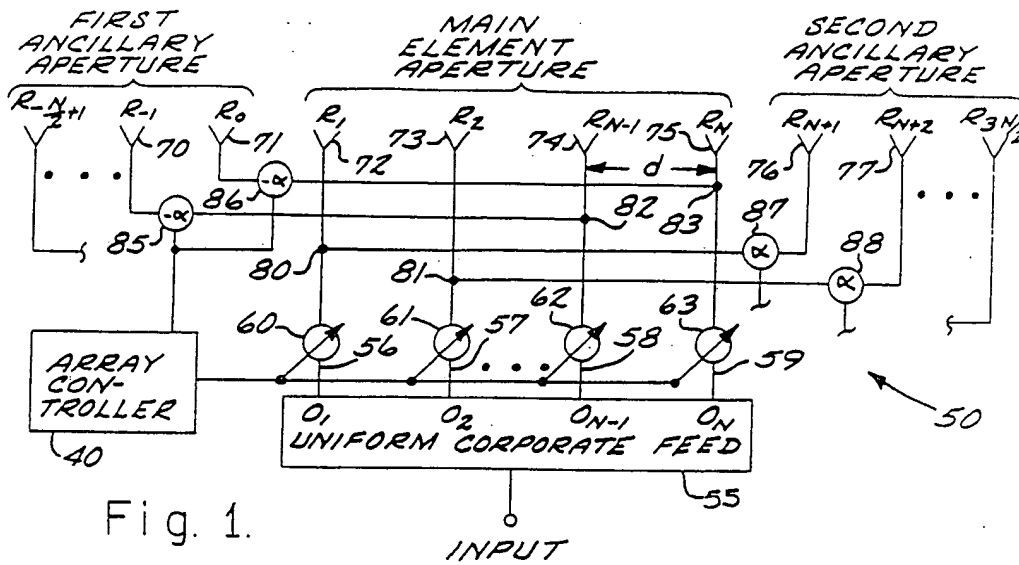
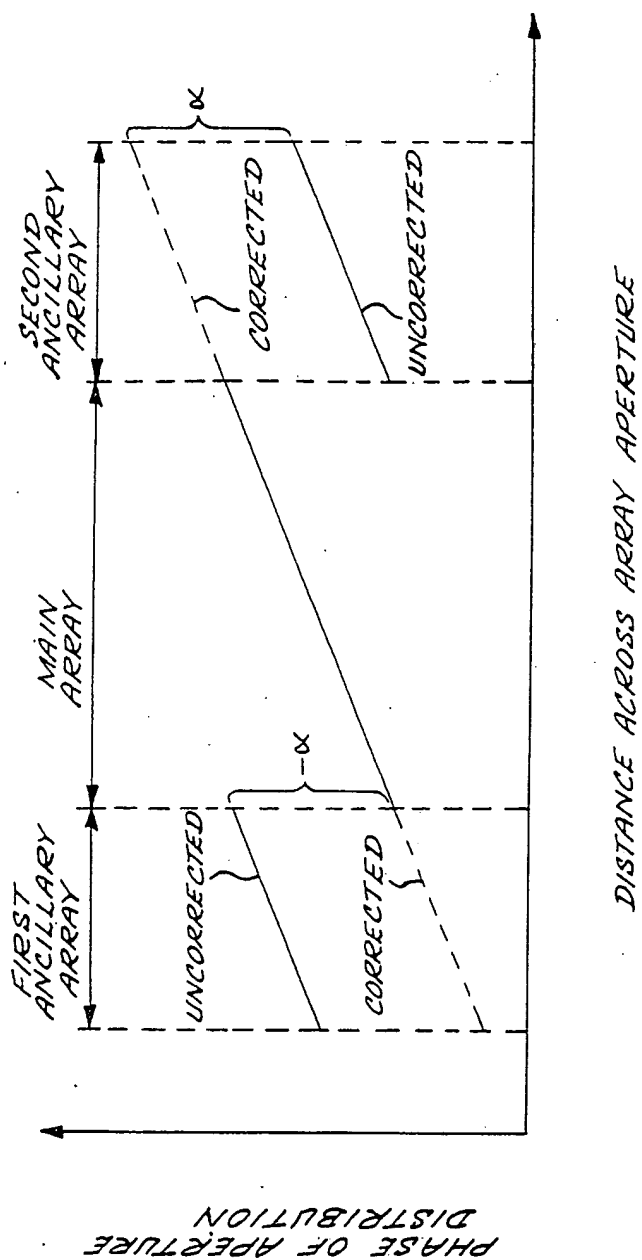
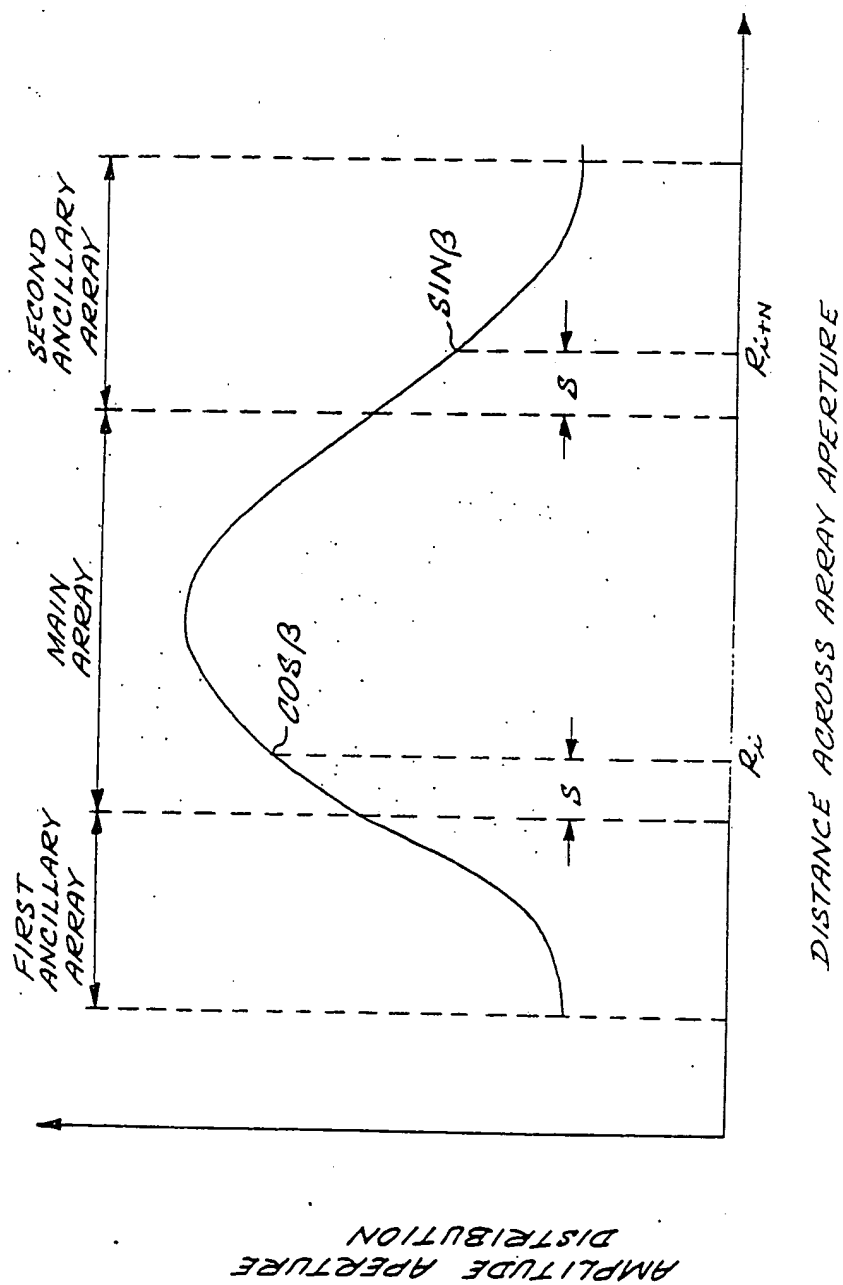


Fig. 2.

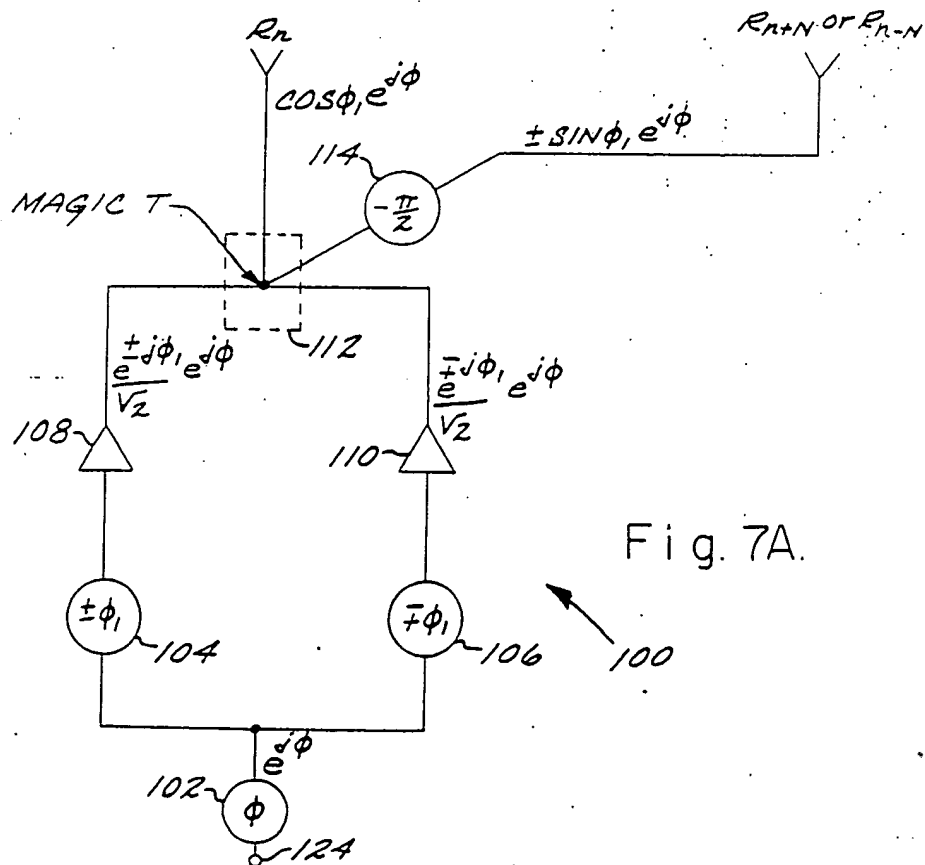
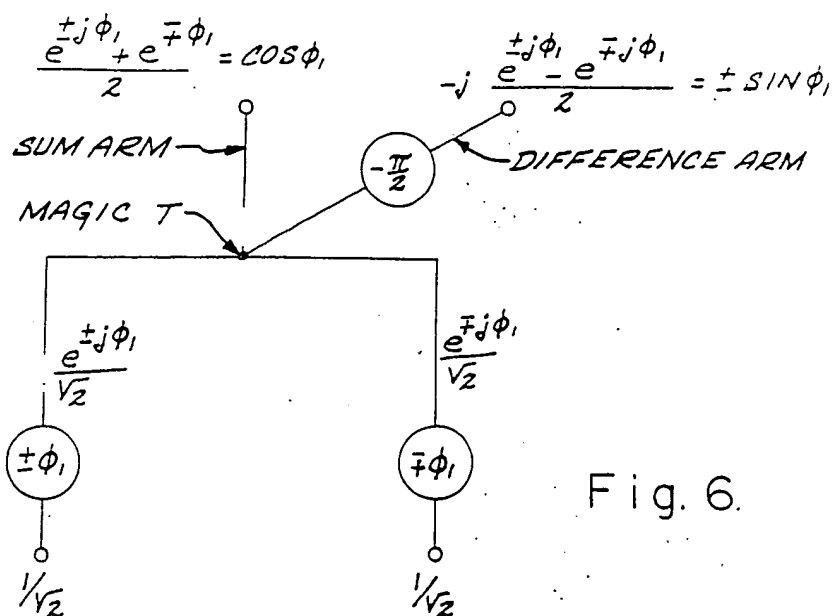


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Fig. 3.



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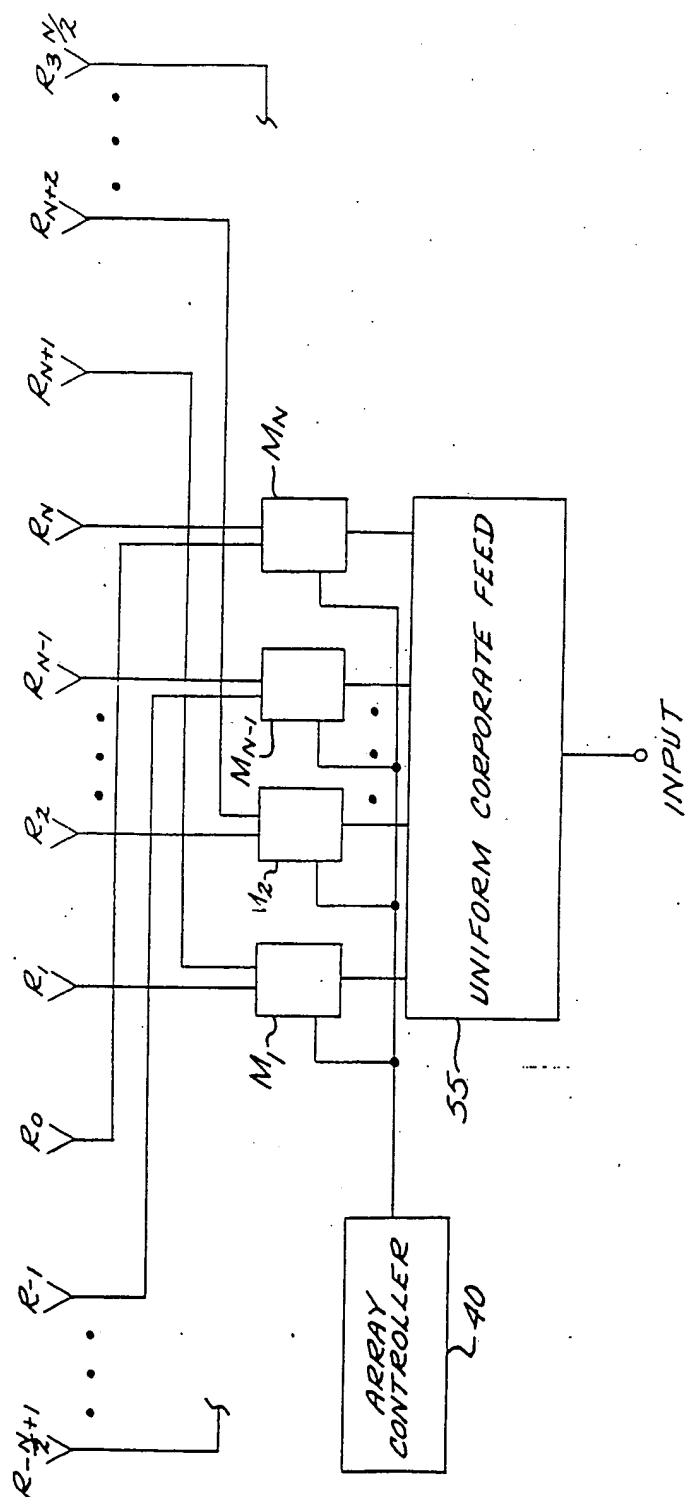


Fig. 7B.

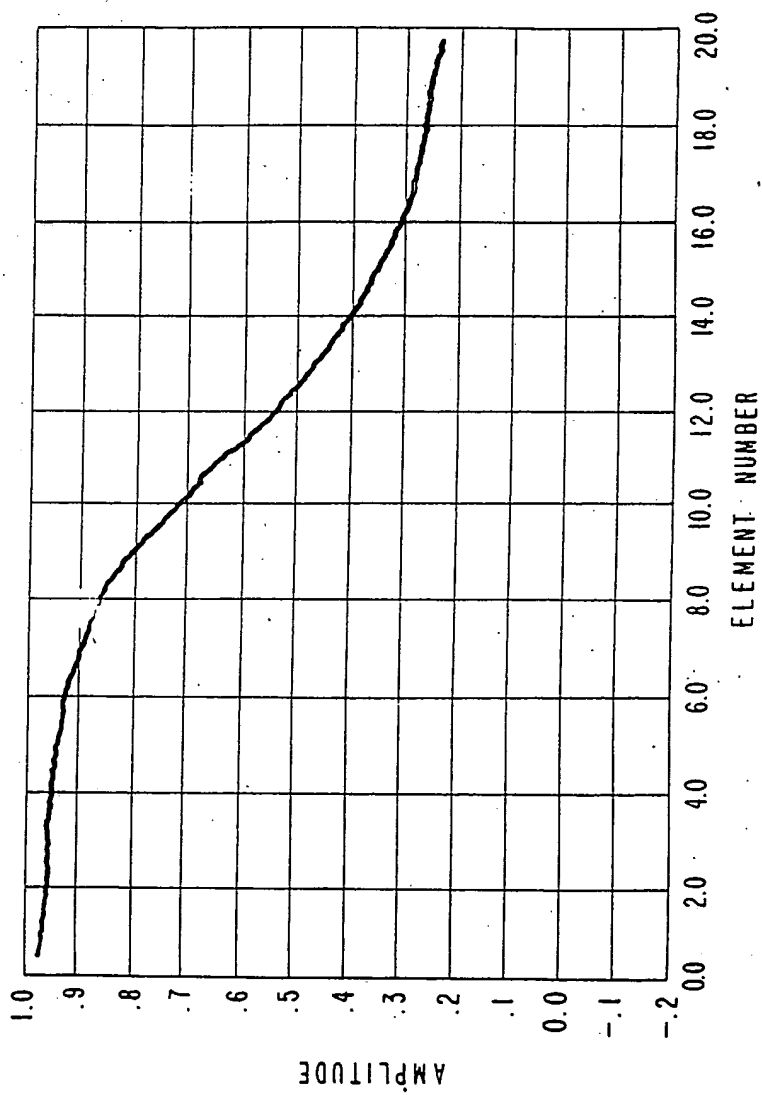


Fig. 8A.

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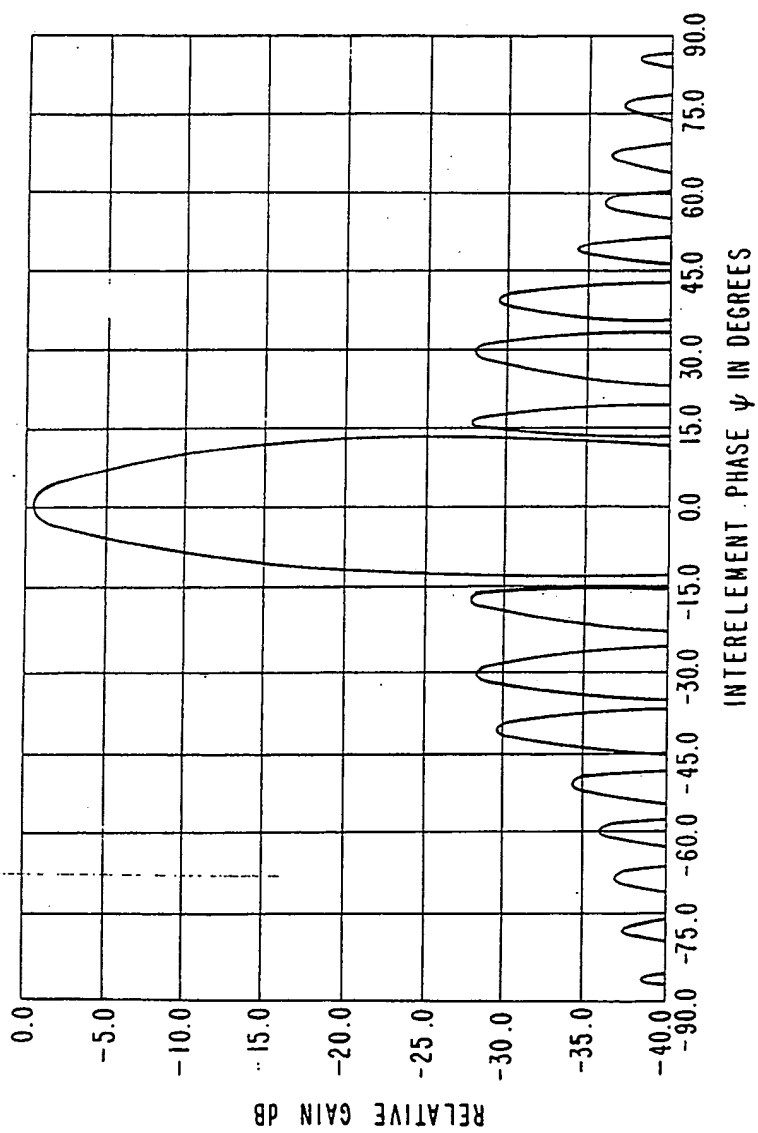
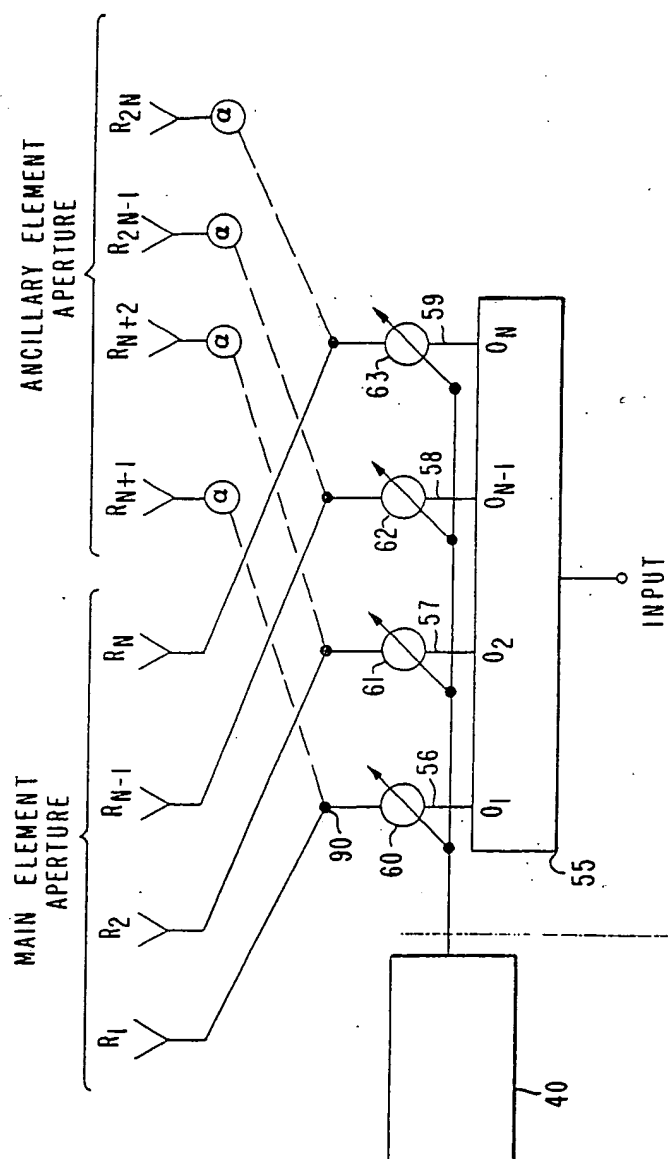
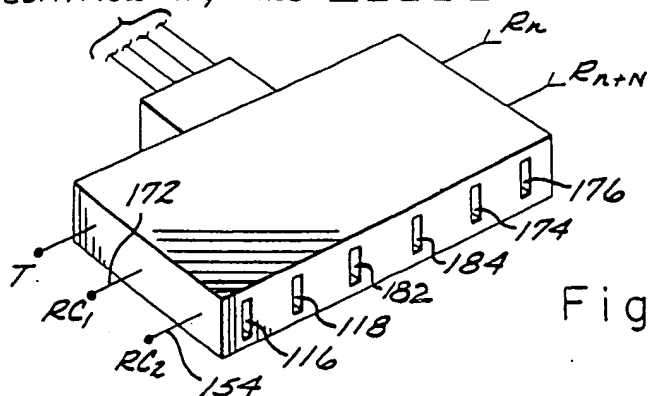
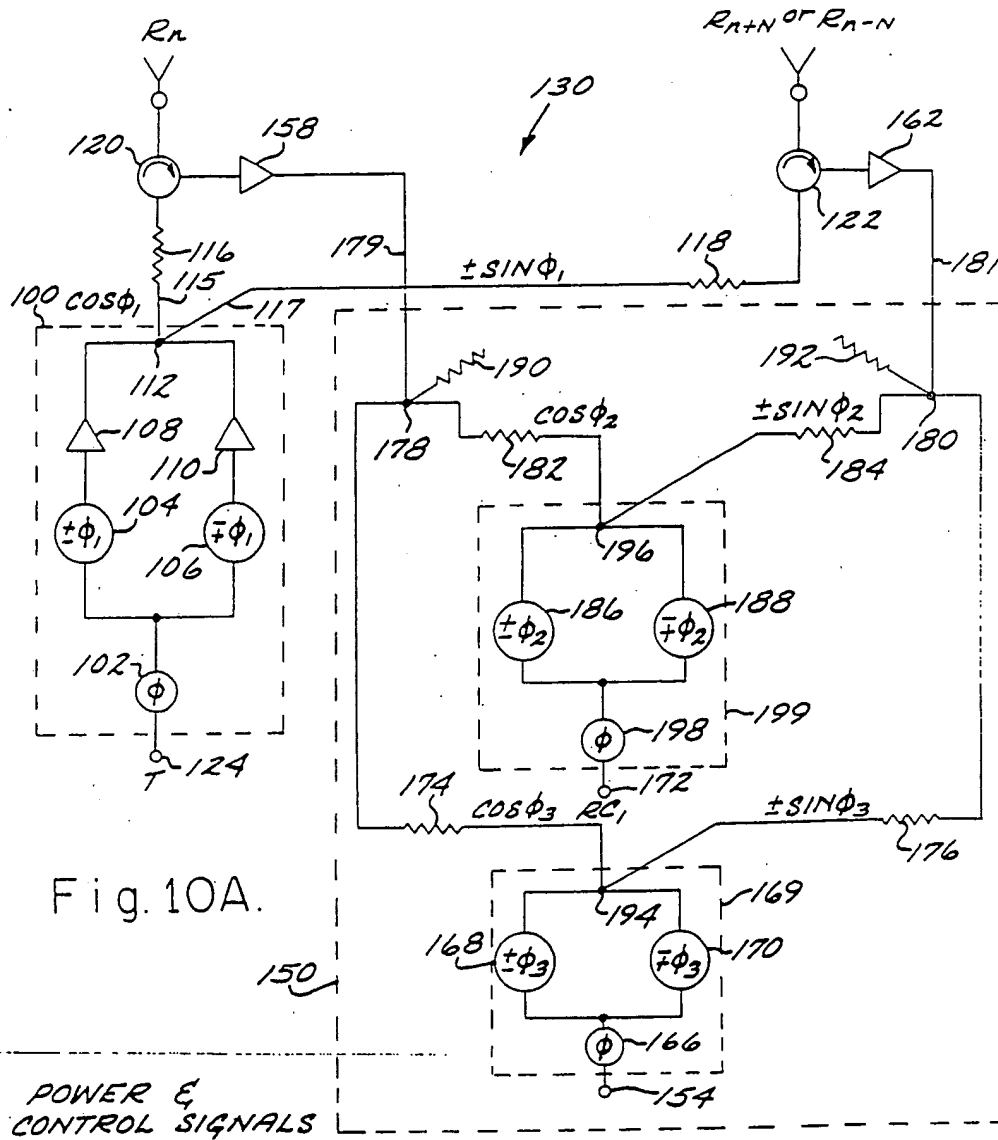


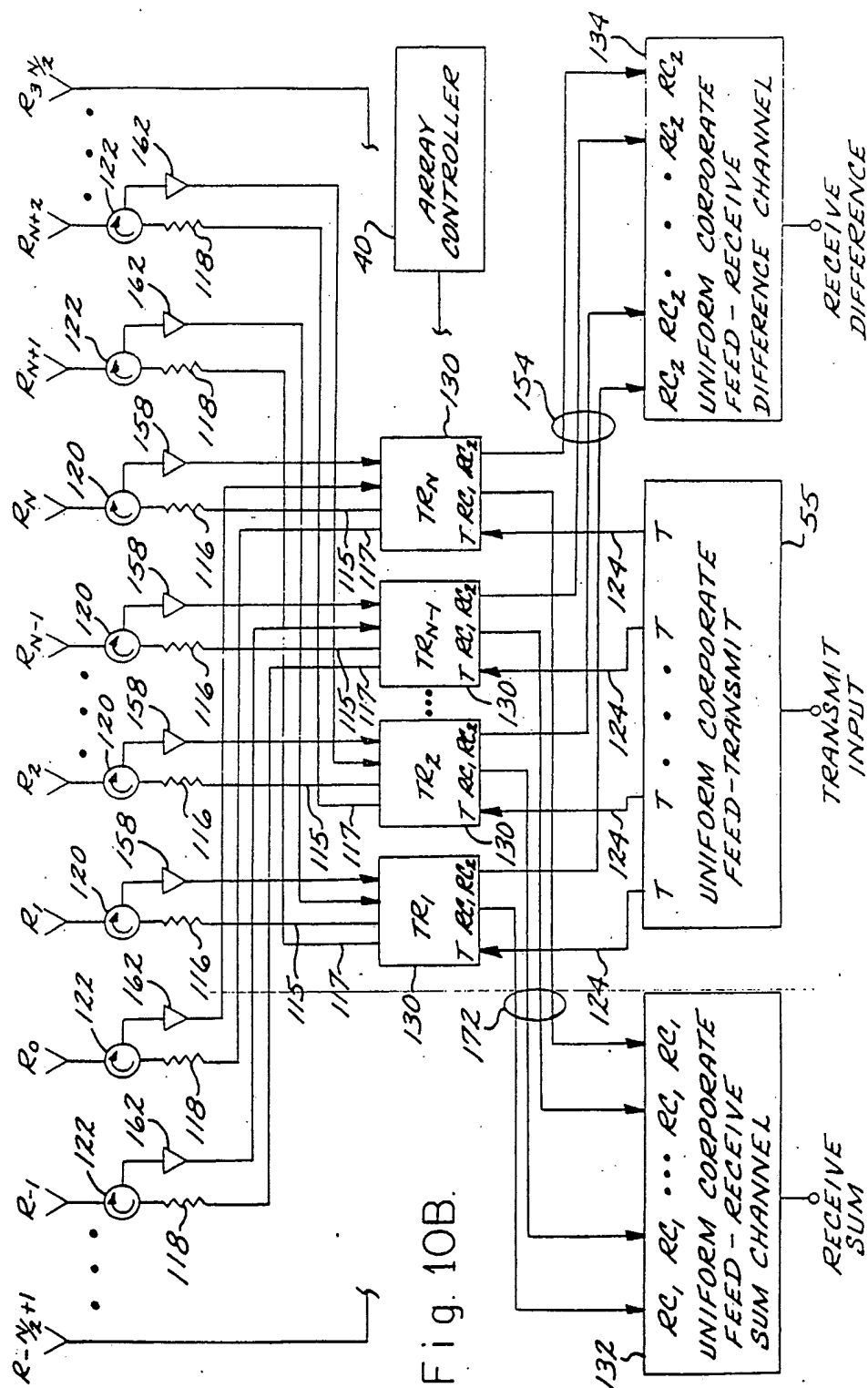
Fig. 8B.



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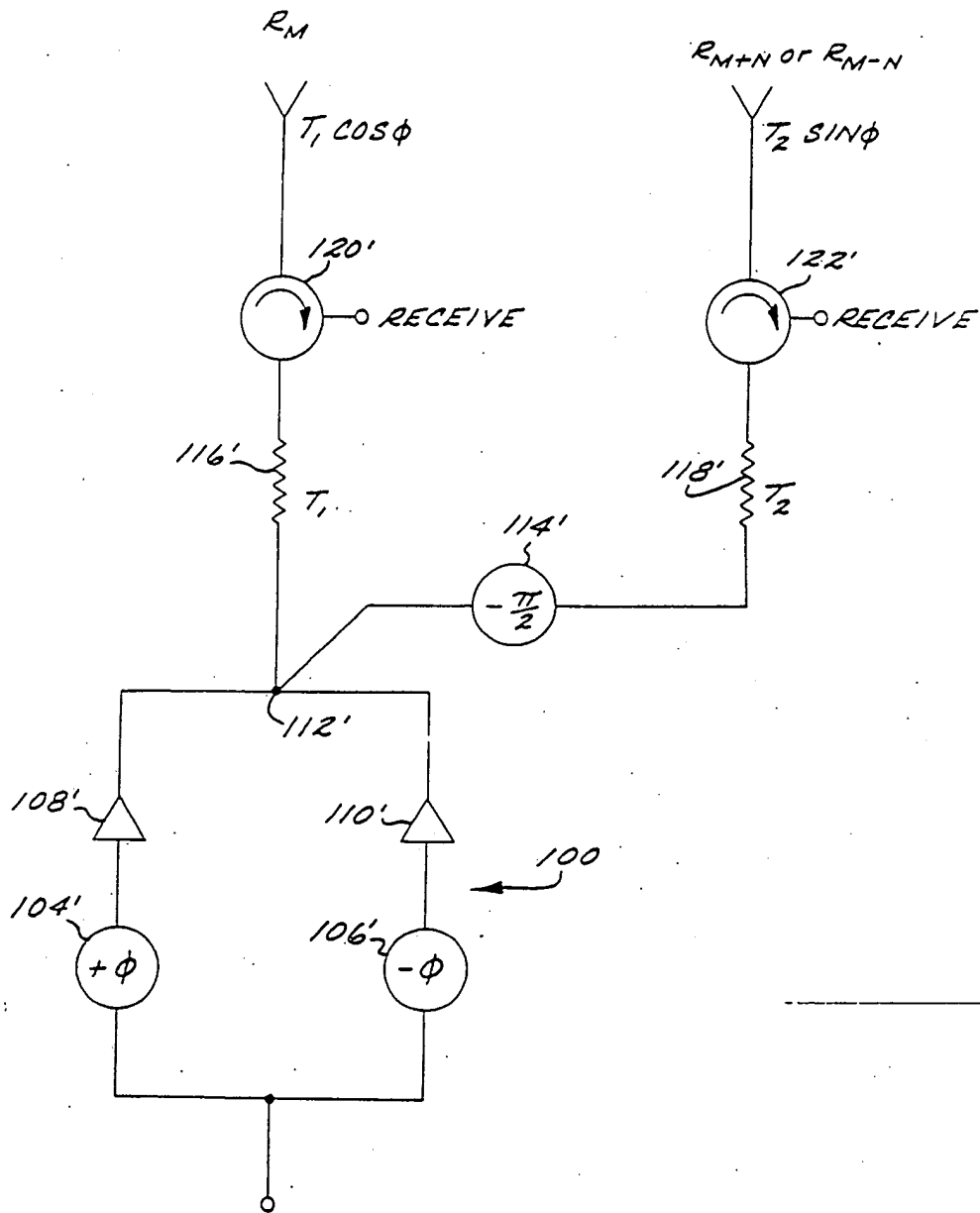


Fig. 12A.

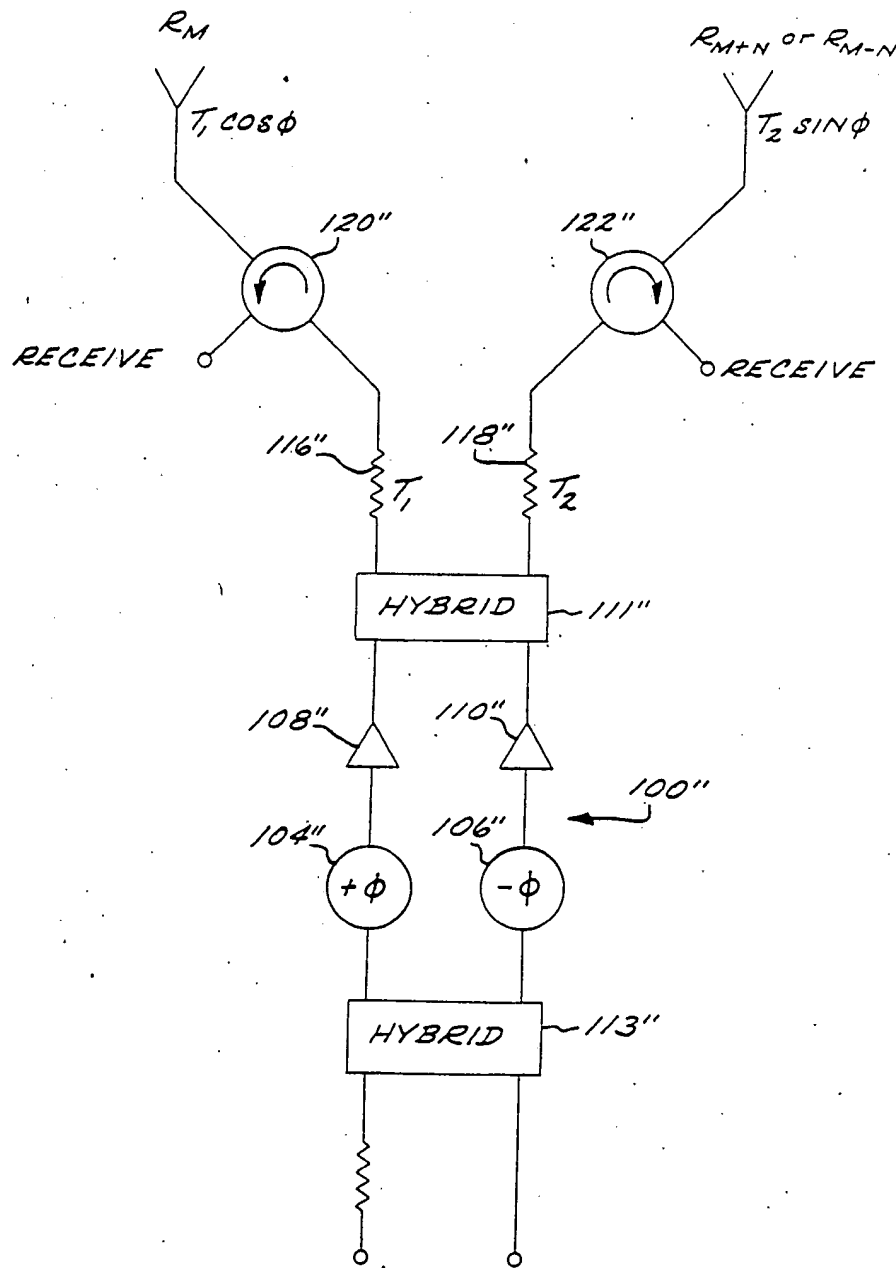


Fig. 12B.

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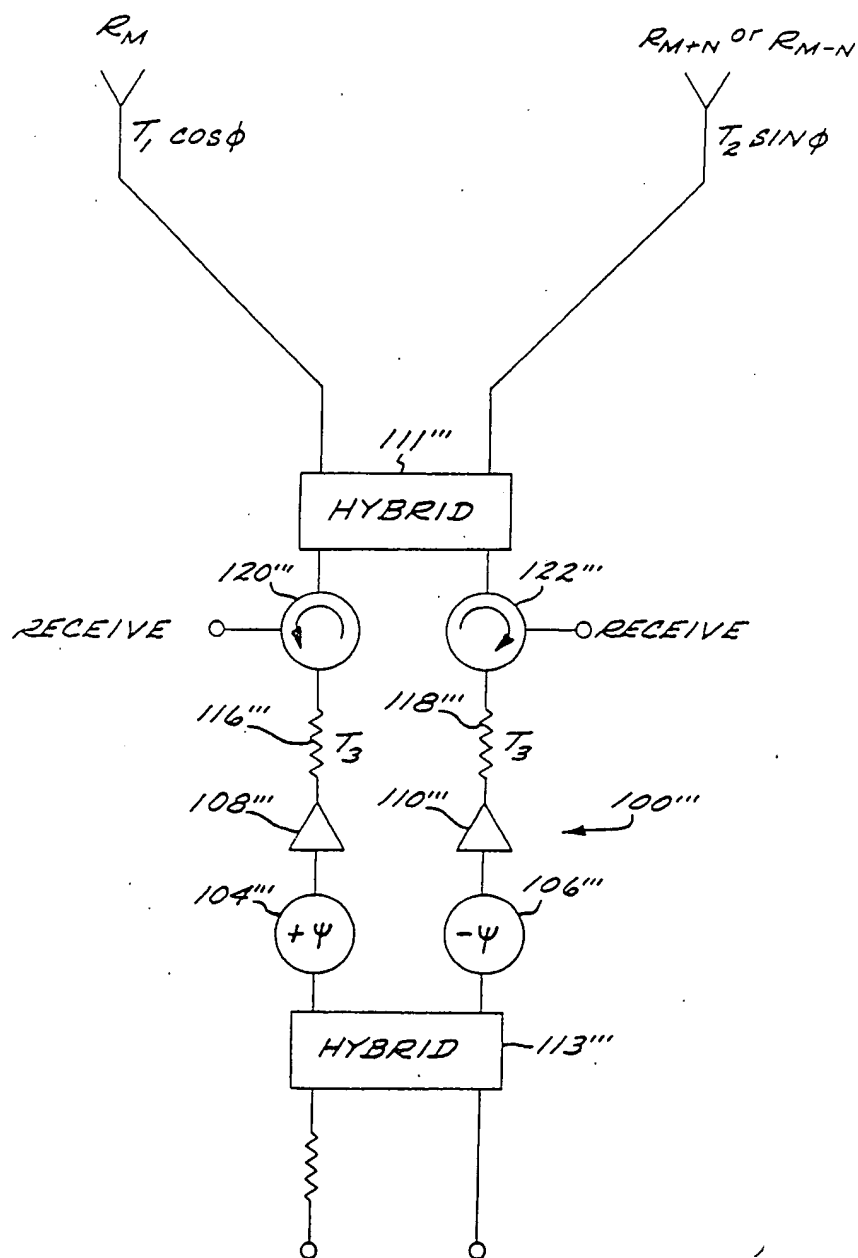


Fig.12C

$$A_{n,m+L} = \pm \sin \beta_2 / \sqrt{2}$$

$$A_{n+N,m} = \pm \sin \beta_1 / \sqrt{2}$$

$$A_{n,m} = \sqrt{\frac{\cos^2 \beta_1 + \cos^2 \beta_2}{2}}$$

Fig. 13.

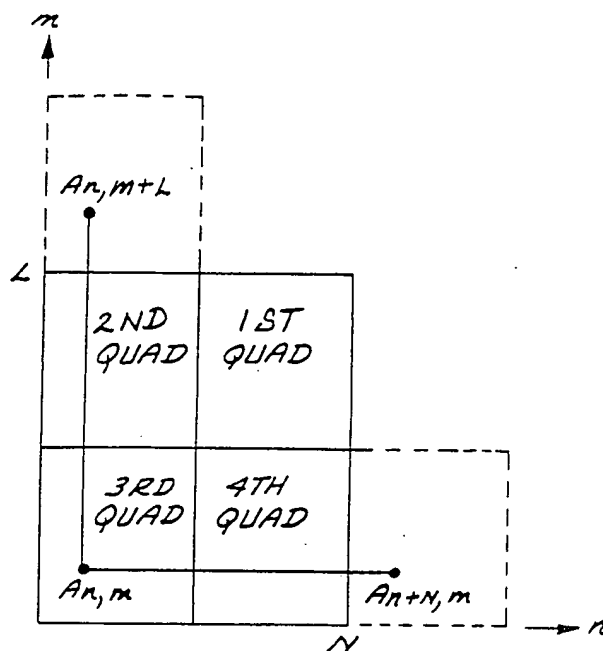
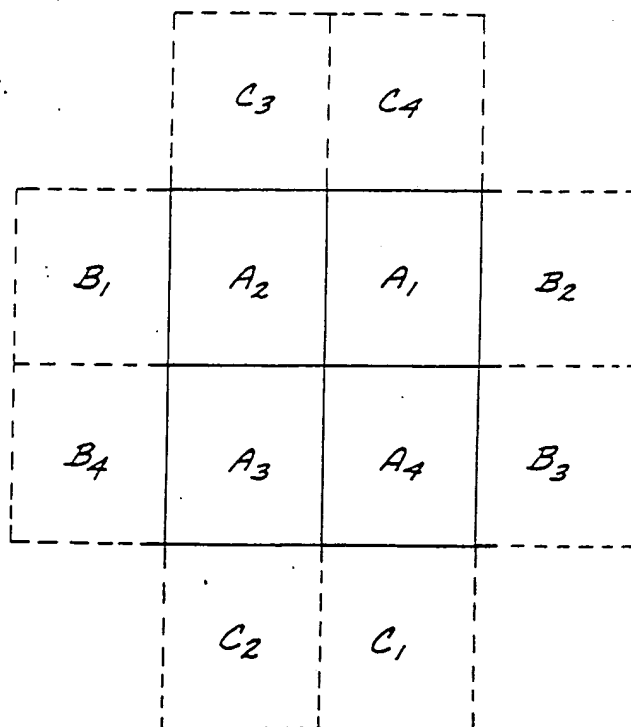


Fig. 14.



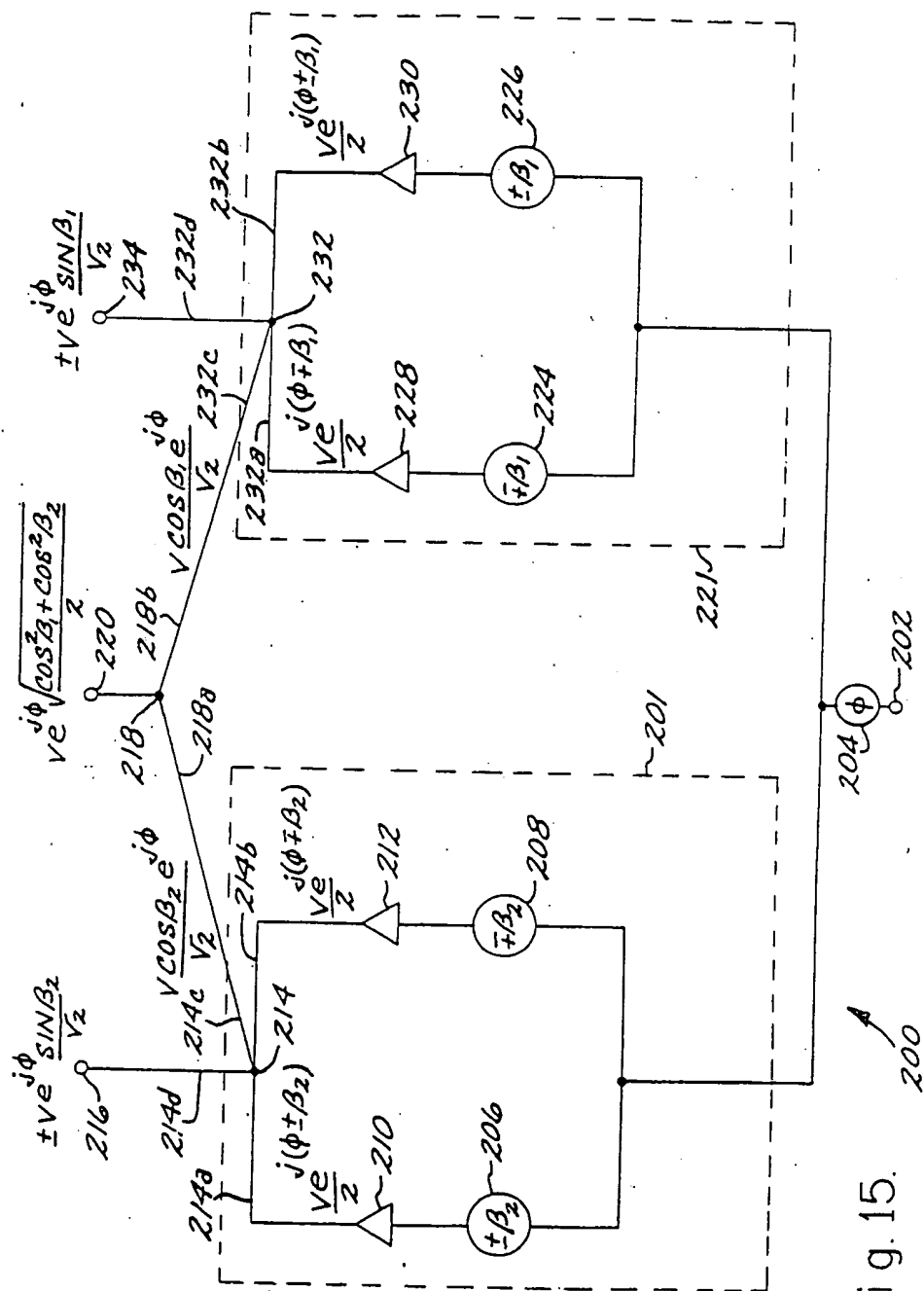


Fig. 15.

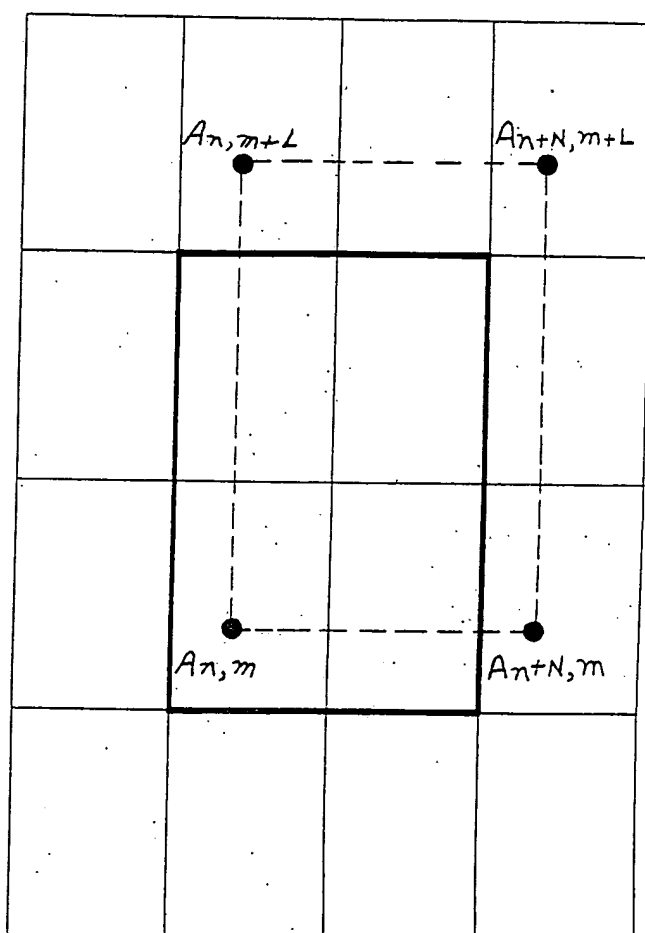
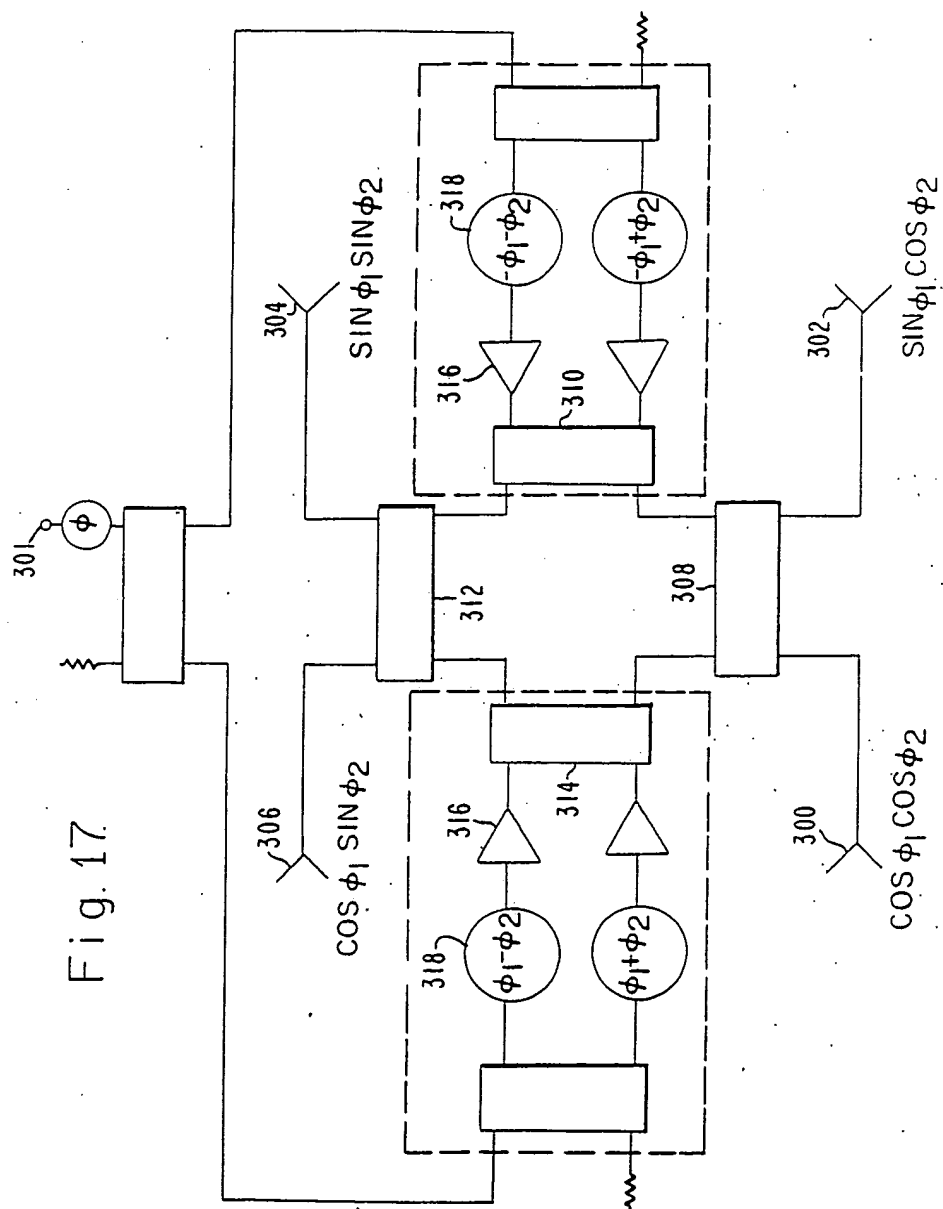
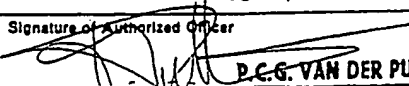


Fig. 16.



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US 88/01242

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) * According to International Patent Classification (IPC) or to both National Classification and IPC IPC ⁴ : H 01 Q 3/36		
II. FIELDS SEARCHED Minimum Documentation Searched ⁷ Classification System Classification Symbols IPC ⁴ H 01 Q Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched *		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹		
Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
Y	IEEE Transactions on Antennas and Propagation, volume AP-18, no. 6, November 1970, H.E. Foster et al.: "Butler network extension to any number of antenna ports", pages 818-820 see the whole document	1, 6, 7
Y	GEC Journal of Research, volume 3, no. 4, 1985, (Chelmsford, Essex, GB), N. Easton et al.: "A solid state transmitter with adaptive beamforming", pages 261-267 see the whole document	1, 6, 7
A	US, A, 3750175 (R.M. LOCKERD et al.) 31 July 1973 see figures 2-4; column 1, line 39 - column 2, line 33; column 3, line 55 - column 5, line 10	1, 2
A	US, A, 3422438 (A.E. MARSTON) 14 January 1969	
<p>* Special categories of cited documents: ¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"A" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search 26th August 1988		Date of Mailing of this International Search Report 16 SEP 1988
International Searching Authority EUROPEAN PATENT OFFICE		Signature of Authorized Officer  P.C.G. VAN DER PUTTEN

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.

US 8801242

SA 22811

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 3750175	31-07-73	NL-A- 6813136	17-06-69
		FR-A- 1579889	29-08-69
		US-A- 3553693	05-01-71
		GB-A- 1232480	19-05-71
		DE-A- 1791091	24-02-72
US-A- 3422438	14-01-69	US-A- 3457509	22-07-69

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